Material Efficiency & Resource Conservation

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Material Use Indicators for Measuring Resource Productivity and Environmental Impacts

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Background paper

Contents

Tables

Figures

1 Introduction

1.1 Policy support for sustainable resource management in Germany

The German government intends to assess the applicability of macro indicators measuring the use of resources by the German economy and requests suggestions for further use and development. In a broader context, this relates to the development of a national programme for sustainable resource management, which is, for instance, requested by the EU´s Thematic Strategy for Sustainble Use of Natural Resources. More specifically, the existing monitoring of progress towards sustainability in pursuit of the national strategy for sustainable development shall be improved.

The German Sustainability Strategy comprises 21 key indicators covering environmental, economic and social aspects (Federal Government 2002). Environmental indicators are GHG emissions, share of renewable energies, growth of settlement and infrastructure land use, species diversity and quality of landscape, nitrogen surplus, share of organic farming, and air pollution. These indicators are focussing on the development within Germany, although the Statistical Office of Germany also accounts for indirect GHG emissions associated with imports and exports (Schoer et al. 2007).

Number 1 indicator of the German sustainability strategy aims to monitor the decoupling of economic growth from resource use (targets in brackets):

1a energy productivity (doubling from 1990 to 2020)

1b raw material productivity (doubling from 1994 to 2020)

Raw material productivity is measured as GDP/(DMI - Biomass). Thus, the indicator is lacking information on indirect resource requirements of imports and on biomass. Therefore, the German government searches for a more comprehensive indicator on the physical side. In this context, questions of the debate are:

- How far shall the system boundary be extended? Shall the indicator account also for unused extraction which has no economic value but also exerts a certain pressure to the environment?
- Shall different environmental impacts be considered within a resource use and productivity indicator or by a separate impact oriented index of material consumption?

1.2 Requirements for indicators

Based on year-long experience in the derivation of indicators, the OECD (2008) addresses the criteria and desirable properties of indicators:

- Simplicity and ease of understanding:
  - should provide information and decision support;
  - numbers should be limited;
    - indicators should be "directionally safe" with regard to the issue they address;
      - should be embedded in a solid data basis;
      - should be founded on sound scientific grounds and theoretical frameworks;
- Acceptance and credibility
  - messages conveyed should be credible;
  - indicators should be accepted and legitimate in the eyes of the users;
  - hould benefit from a consensus about their validity.

For new indicators, naturally criteria such as acceptance and consensus will have to develop, such as the data base.

Before that general background, OECD (2008, p. 72) specifies the basic selection and validation criteria (Tab. 1-1).

It is also stressed, that indicators need to be interpreted with regard to their target question(s), set into context, and must not be over-interpreted.

Tab. 1-1: Selection criteria for material flow indicators (OECD 2008)

POLICY RELEVANCE AND UTILITY FOR USERS	
A MF indicator should: ♦ Provide a representative picture of material flows and their interactions with the environment and the economy; ♦ Be simple, easy to interpret and able to show trends over time; ♦ Be responsive to changes in economic activities, resource productivity, technology development and the environment; ♦ Have a threshold or reference value against which to compare it, so that users can assess the significance of the values associated with it; ♦ Provide a basis for international comparisons; ♦ Be either national in scope or applicable to sub-national issues of national significance. ♦ Lend itself to being adapted to specific national and sub-national circumstances.	Particular aspects to be considered: ♦ The environmental and economic significance of MF indicators: – the relation to environmental pressures or impacts – the relation to economic and trade related issues ♦ The choice of appropriate reference values to which MF indicators can be compared ♦ The level of aggregation/detail of MF indicators. – Sets of indicators that collectively give the necessary insights versus a highly aggregated indicators. ♦ The country-specific factors that have a bearing on the significance of MF indicators
ANALYTICAL SOUNDNESS	
A MF indicator should: ♦ Be theoretically well founded in technical and scientific terms; ♦ Be based on international standards and international consensus about its validity; ♦ Lend itself to being linked to economic and environmental models, forecasting and information systems.	Particular aspects to be considered: ♦ The internal coherence of MF indicators ♦ The external coherence of MF indicators: – with national accounts aggregates; – with productivity measures such as capital productivity, labour productivity, multi-factor productivity; ♦ The additivity of MF variables to enable the calculation of regional aggregates (for the OECD as a whole or for OECD regions, for the European Union, for the G8, for world regions).
MEASURABILITY	
The data required to support the indicator should be: ♦ Readily accessible or made available at a reasonable cost/benefit ratio; ♦ Adequately documented and of known quality; ♦ Updated at regular intervals in accordance with reliable procedures.	Particular aspects to be considered: ♦ The level of ambition pursued and the choice of the data sources to be used. ♦ Data accuracy (completeness and statistical uncertainties) due to the indirect measurement of certain MF variables. This is especially important for certain aggregated EW-MF indicators and their interpretation.

a) Based on OECD (1993).
b) These criteria describe the "ideal" indicator; not all of them will be met in practice.
Source: OECD.

1.3 Material flow analysis and derived indicators

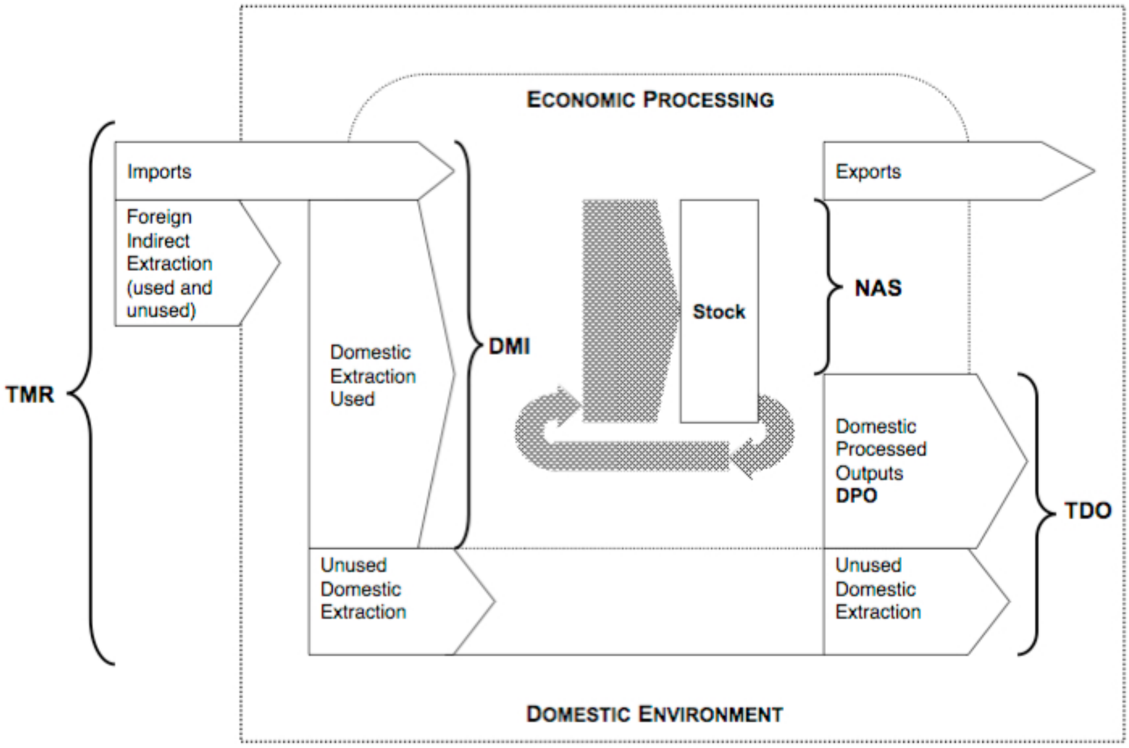
Material flow based analyses are used to answer various target questions and different scales, ranging from selected substances, materials, products, to companies, sectors and whole economies (Fig. 1-1). Macro indicators are focussing on the development at the country level. Nevertheless, with regard to implementation of related targets at the sector and company/product level it seems important that the macro level indicators are also applicable at these other levels.

Fig. 1-1: Material flow based analyses and related issues of concern (OECD 2008 based on Bringezu and Moriguchi 2002)

Issues of concern	Specific concerns related to environmental impacts, supply security, technology development			General environmental and economic concerns related to the throughput		
	within certain businesses, economic activities, countries, regions			of substances, materials, manufactured goods		
	associated with			*at the level of*		
Objects of primary interest	Substances	Materials	Products (manufactured goods)	Businesses	Economic activities	Countries, regions
	chemical elements or compounds e.g. Cd, Cl, Pb, Zn, Hg, N, P, C, CO2, CFC	raw materials and semi-finished goods e.g. energy carriers, metals (ferrous, non-ferrous), sand and gravel, timber, plastics	e.g. batteries, cars, computers	e.g. establishments, plants, small and medium sized enterprises, multi-national enterprises	e.g. mining, construction, chemical industry, iron and steel industry	e.g. aggregate mass of materials (& related materials mix), groups of materials, selected materials
Type of analysis	Ia Substance Flow Analysis	Ib Material System Analysis	Ic Life Cycle Assessment	IIa Business level MF analysis	IIb Input-Output Analysis	IIc Economy-wide MF Analysis
	⇕	⇕	⇕	⇕	⇕	⇕
Type of measurement tool	Substance Flow Accounts ✪	Individual Material Flow Accounts ✪	Life Cycle Inventories	Business Material flow accounts	Physical Input-Output Tables ✪ ⦿, NAMEA-type approaches ⦿	Economy-wide Material Flow Accounts ✪

✪: MFA tools using the materials balance principle. ⦿: MFA tools using national accounting principles fully in line with the SEEA.

Fig. 1-2: Scheme of the socio-industrial metabolism at the level of Economy-wide MFA (after Matthews et al. 2000)



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Economy-wide Material Flow Analysis (ew-MFA) accounts for material use of a country by providing a set of indicators which - in a complementary manner - provide information on essential characteristics of the socio-industrial metabolism (Fig. 1-2).

For the assessment of single types of indicators it seems valuable to consider the specific information conveyed in relation to the status and dynamics of the metabolism:

Input indicators

Input indicators measure those materials that enter the socio-industrial metabolism to support activities within the economy, mainly to extract those materials from the environment which are used for production and consumption. They include: Direct Material Input (DMI), and Total Material Requirement (TMR).

Output indicators

Output indicators account for those materials that have been used or moved for production and consumption purposes, and are subsequently leaving the system either in the form of emissions and waste, or in the form of exports. Output indicators include: Domestic Processed Output (DPO), Total Material Output (TMO) and Total Domestic Output (TDO).

Consumption indicators

Consumption indicators describe those materials that are moved for or used within the domestic economy for consumption purposes. They include: Domestic Material Consumption (DMC) and Total Material Consumption (TMC). As they only consider the material and resource flows associated with domestic consumption, the DMC and TMC can be calculated by subtracting exports (and their associated indirect flows for the TMC) from the DMI and TMR respectively. TMC thus measures all primary material requirements of domestic or foreign resources, which are attributable to domestic consumption.

Balance indicators

The Net Additions to Stock (NAS) measures the physical growth of the economy, which reflects the difference between inputs and outputs[1]. The Physical Trade Balance (PTB) measures the physical trade surplus or deficit of an economy and is defined as imports minus exports (excl. or incl. of their hidden flows).

[1] Theoretically, the difference may become negative which would reflect a development of declining material stocks

Productivity indicators

Productivity indicators can be constructed by combining a desired outcome with economy-wide MFA indicators. If the desired outcome is an economic performance indicator, information about the eco-efficiency of the economy can be provided. The GDP per DMI, for example, indicates the (direct) material productivity, whereas the GDP per TMR is a measure of the resource (total material) productivity. Monitoring productivity indicators over time allows examination of the way in which decoupling of material and/or resource use from economic growth resp. value added has occurred.

Consistency indicators

Consistency indicators are still under development. They indicate the degree to which anthropogenic material flows are embedded in natural systems in a sustainable way, which allows for the continued use of materials without overstressing absorption or regeneration functions. A proxy for such an indicator could, for instance, be the share of renewables in DMI stemming from sustainable cultivation schemes.

With regard to the concerns driving the establishment and use of macro indicators, OECD (2008) distinguishes the following fields of main interest (after OECD 2008):

Fig. 1-3: Establishment and use of macro indicators - fields of main interest (after OECD 2008)

❶ Monitoring the <u>material basis</u> of national economies and industries.
This requires indicators that reflect the level and characteristics of materials use in the economy or in industries (and process chains).

❷ Monitoring the <u>material productivity</u> of national economies and industries.
This requires indicators that reflect the intensity of materials use in the economy or in industries (and process chains), and that can be linked to productivity issues and eco-efficiency measures.

❸ Monitoring the interactions of <u>trade and globalisation</u> with material flows.
This requires indicators that reflect international movements and trade in materials (raw materials, semi-finished goods, materials embodied in finished goods, recyclable materials, hazardous materials) and that can be linked to issues of foreign outsourcing, demand and supply issues, and environmental risks and safety issues.

❹ Monitoring the <u>management</u> of selected natural resources and materials.
This requires indicators that reflect developments in selected materials that raise concerns as to the environmental consequences of their production and use, the adequacy of their supply, or the effectiveness of their management. Such indicators can be linked to issues of natural resource management, biodiversity, waste and materials management, as well as to specific resource productivity issues.

❺ Monitoring the <u>environmental impacts</u> of materials use (overall and specific).
This requires indicators that reflect developments in materials that raise concerns as to the environmental consequences of their production and use. Such indicators can be linked to issues of toxic contamination, environmental health, biodiversity, waste management, but also to natural resource management.

Concerns (1) and (2) may be extended towards the interest in the resource basis and resource productivity of national economies and industries, which would imply the extension of the system boundary towards the interface of nature and technosphere. Whereas material use could relate to any material used within the technosphere and economy, resource use generally means to account for the material use in terms of all up-stream extractions of primary materials, i.e. material resources, required to deliver these materials.

There are different relations possible between GDP as divisor and material or resource input indicators as denominator (Tab. 1-2). Which physical indicator is chosen depends on the target interpretation required. There are formal arguments that the physical indicators should be defined in the same manner as GDP, i.e. excluding imports; on the other hand, there is the basic argument that an indicator should be chosen with regard to the main concern. If the concern comprises the political intention to monitor the resource productivity also with regard to the global resources used for the production of domestic final consumption or export, then the imports and their indirect flows need to be included. In that sense, GDP/DMI and GDP/TMR would be adequate to indicate (direct) material productivity and total material productivity, resp. In contrast, DMC and TMC would be more adequate to indicate the absolute level of (domestic) material consumption and total material consumption, resp..

Tab. 1-2: Possible relations to measure material and resource productivity (OECD 2008)

Type of input measure / Type output measure	***Direct Material Input or Raw Material Input***	***Total Material Requirement (incl. indirect flows)***	***Domestic Material Consumption or Raw Material Consumption***	***Total Material Consumption (incl. indirect flows)***
GDP, Value added	Direct Material Productivity GDP/DMI Direct Raw material Productivity GDP/RMI	Total Material Productivity GDP/TMR	Domestic Material Productivity GDP/DMC Domestic Raw Material productivity GDP/RMC	Total Domestic Material Productivity GDP/TMC

The OECD (2008) distinguishes two broad groups of indicators:

Fig. 1-4: Generic and issue-specific indicators (OECD 2008)

Generic indicators

The most common national MF indicators in use can be derived from simple economy-wide MFAcc considering only flows of materials entering the economy (input flows), without the need to compile a complete material balance. They usually represent medium to top-level aggregates of the accounting variables, with top-level aggregates covering all materials, except water and air.

Most OECD countries that have developed a national set of environmental or sustainable development indicators include in their set one or several indicators derived from simple national EW-MFAcc. These indicators are best suited for supporting broader policy considerations. They often serve general information and communication purposes, and contribute to raising awareness. They are less suited for supporting policy analysis, unless complemented with more detailed statistics (e.g. on MF by economic activity) or broken down into their constituent variables, by material groups (e.g. metals, construction minerals, fossil fuels, woody and other biomass) or by flow type (e.g. used and unused material flows, primary and secondary raw materials).

Issue-specific indicators

Similar, but more specific indicators reflecting particular problems can be derived from more sophisticated MFA tools such as material system analysis (MSA), substance flow accounts and analysis (SFA), life cycle assessments (LCA) and extended input-output analysis (eIOA) or from comprehensive national MFAcc. A higher level of detail can be reached with regard to:

- economic activities, industries, enterprises, product groups (meso level) down to life-cycle-inventories and analyses of specific products;
- specific materials and substances and the analysis of related flows;
- a combination of these two types of breakdowns,

The generic indicators provide information on the structure and volume of the metabolism (input, output, balance, productivity etc.), and the "broader policy considerations" can be long-term targets to sustain that metabolism, e.g. by reducing the input to levels which are deemed more sustainable, or towards a flow equilibrium of input and output. The issue specific indicators relate to particular problems and related material and substance flows, e.g. GHG emissions and global warming.

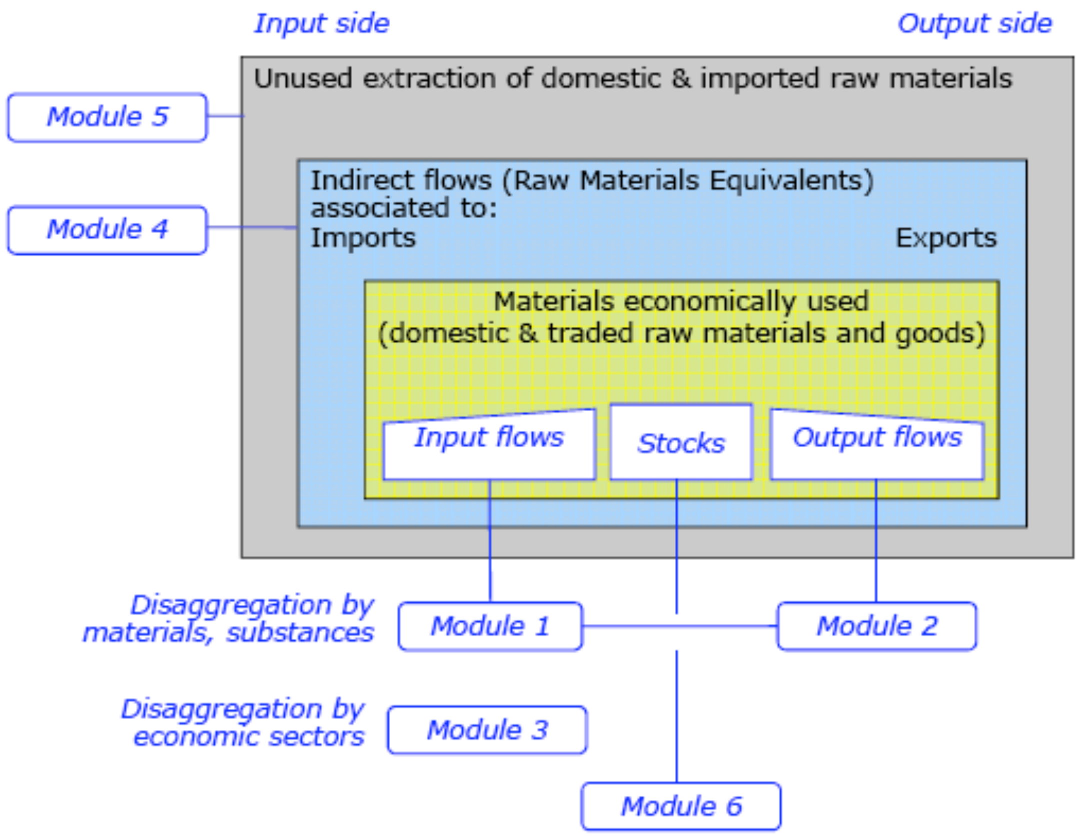
Sustaining the socio-industrial metabolism would require both

- the adjustment of the structure and volume of the overall metabolism (and related land use pattern) which can be uphold for a longer period without impairing the co-evolution with natural systems;
- the reduction of specific environmental pressures below acceptable levels (e.g. GHG, ODP, eutrophication).

1.4 Development of the MFA accounting framework

A fast development of ew-MFA took place since the beginning of the1990s, and standard framework for official statistics have meanwhile be established by Eurostat (2001, 2009) and the OECD (2008). These frameworks foresee a stepwise approach through the establishment of indicators (Fig. 1-5; Tab. 1-3), starting with indicators which can easily be supplied but have limited information value (e.g. DMI and DMC), and proceeding towards more challenging indicators which provide a more comprehensive information (e.g. TMR and TMC), in particular, an information which minimizes the risk of problem shifting (towards categories of flows which are not yet accounted for, e.g. biomass, unused extraction, indirect flows of imports/exports).

Fig. 1-5: Modules of a system of national material flow accounts (OECD 2008)



Thus, when focussing on the input side in order to account for material and resource use and productivity, the statistical framework foresees three steps:

1. DMI and DMC (without indirect flows of trade, and without unused extraction)
2. DMI and DMC in Raw Material Equivalents (RME) (incl. indirect flows of used extraction)

3. TMR and TMC (incl. used and unused extraction as well as indirect flows of both)

Each of these indicators provides a different information. They are therefore complementary rather than competitive. The basic characteristics are listed in the indicator briefs below.

Concerning the consideration of indirect flows of imports and exports, these are prerequisites in order to monitor shifts between domestic and foreign material/resource use.

As regards the distinction of used and unused extraction, it seem important to note that this is an economic classification which is not necessarily relevant for environmental impacts. The environmental pressure associated with resource extraction is often related to the overall extraction volume or mass, e.g. in terms of landscape change and groundwater impairment, whereas the part of the extraction which has an economic value is relative small. Thus, neglecting unused extraction may be misleading in particular for (rare) metals. With regard to the system boundary, accounting for DMI-RME would reflect the *output* of the first processing, whereas considering used and unused extraction would reflect the *input* to the first processing in physical terms.

As a consequence, any selection of an indicator will require a decision about a target questions to be prioritised, as well as a consideration of the feasibility of regular application (data availability and effort of compilation).

Nevertheless, the development of material use towards resource use and productivity indicators seem to be relative straightforward, from narrow towards sufficiently comprehensive indicators.

Tab. 1-3: Attribution of material flow indicators to accounting modules (OECD 2008)

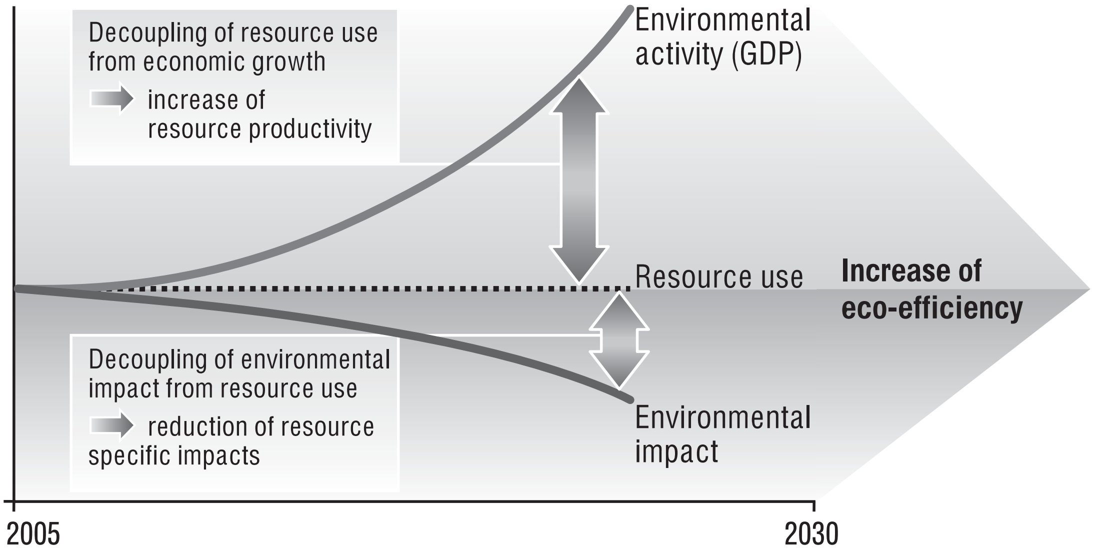
No. of the module	Basic MF indicators and related accounting variables	Efficiency indicators*	Other MF indicators and indicators for particular material flows
Module 1	Domestic extraction (DE) Imports (IM) Direct material input (DMI)	GDP* per DMI	DMI per capita DEU per area IMP per DMI DEU per DMI IMP per price of imports Share of renewables in DEU Share of renewables in DMI DMI_{REC} Flows of particular interest
Module 2	Exports (EXP) Emissions and wastes (EW) Dissipative use of products (DUP) Domestic material consumption (DMC) Domestic processed output (DPO) Net additions to stock (NAS) Physical trade balance (PTB)	GDP* per DMC GDP* per DPO	DMC per capita DPO per capita DMC per area DPO per area NAS per area IMP per DMC DEU per DMC EW per DPO DUP per DPO EXP per price of exports Flows of particular interest
Module 3	DMI by economic sectors DMC by economic sectors DPO by economic sectors	Gross value added* of particular sector per sectoral DMI Gross value added* of particular sector per sectoral DMC Gross value added* of particular sector per sectoral DPO	Flows of particular interest
Module 4	Raw material equivalents of imports (RME_{IMP}) Raw material equivalents of exports (RME_{EXP}) Raw material input (RMI) Raw material consumption (RMC) PTB based on RME_{IMP} and RME_{EXP}	GDP* per RMI GDP* per RMC	RMI per capita RMC per capita IMP per RME_{IMP} EXP per RME_{EXP} Share of renewables in RMI Flows of particular interest
Module 5	Unused domestic extraction (UDE) Domestic total material requirement (domestic TMR) Total unused extraction (TUE) Indirect flows of imports (IF_{IMP}) Indirect flows of exports (IF_{EXP}) Total material requirement (TMR) Total material consumption (TMC) PTB based on IF_{IMP} and IF_{EXP}	GDP per TMR GDP per TMC	TMR per capita TMC per capita UDE per domestic TMR TUE per TMR Sum of IMP and IF_{IMP} per TMR Sum of IMP and IF_{IMP} per TMC Sum of DEU and UDE per TMR Sum of DEU and UDE per TMC Share of renewables in TMR TMR_{REC} Flows of particular interest
Module 6	Gross additions to stock (GAS) Net additions to stock (NAS)	n.a.	GAS per DMC incl. input balancing items NAS per area Flows of particular interest

* Depending on the MF variable used, adjustments to the economic variable may be needed to ensure the statistical coherence between the two parts of the ratio.
Source: OECD.

1.5 Considering environmental impacts of material and resource use

On the level of single materials and products, it is obvious that there are different specific life-cycle wide impacts, as can be measured by means of LCIA-type analysis. Therefore, it has been argued that the material composition of an economy should be altered towards a lower overall impact, and therefore, the overall impact of material and resource use should be accounted for. This had particularly been pushed by the European Commission defining a double-decoupling (Fig. 1-6).

Fig. 1-6: The European Resource Strategy aims at a double decoupling



Concluding from individual materials´ environmental profile to the overall impacts of an economy is not straightforward. To mention only a few aspects:

- Materials and products are associated with different environmental profiles which add up to the overall performance of the economy in a way that strengths and weaknesses across production lines often compensate each other;
- Substitution of one material for another also leads to the exchange of the related bundles of specific pressures;
- Shifts between different environmental impacts may not be easy to evaluate;
- Shifts towards impacts which cannot be measured sufficiently will be neglected.

As a consequence, the assumption that environmental impacts - overall - can be effectively decoupled from resource use at the macro level, remains hypothetical for the time being. In order to test the hypothesis, one may try to develop impact oriented indicators which quantify the impacts as far as possible at the macro level. This is the aim of several recent and ongoing studies, commissioned by European institutions and national governments.

Basic challenges for those impact oriented indicators are:

1. The systems definition and the inventory of the materials and resources considered
2. The categorization and quantification of specific environmental impacts
3. The normalization of each impact to compare it with other impacts
4. The relative weighting of different impacts against each other

Two indicator concepts may be used to exemplify those challenges and the options to deal with them. The Environmentally weighted Material Consumption (EMC) and the Environmental Impact Load (EVIL) are desribed in the indicator briefs below.

The ***systems definition*** comprises the definition of the system boundary in functional terms. For life-cycle oriented studies, accounts and indicators that generally considers processes from resource extraction up to final disposal. Those flows are accounted for which pass these processes, thereby crossing the system boundary between environment and the socio-economic system. The scope defines the political-geographic area for which the flows are to be considered, usually for a period of one year. A critical aspect is the selection of flows crossing the system boundary which are accounted for. Both EMC and EVIL *select a limited number of base materials* for which the environmental profiles of impacts from cradle-to-material and resulting waste-to-final disposal are considered (the use phase being considered indirectly by consumption of energetic materials). As a consequence, there remains a rest of unconsidered flows the relevance of which remains to be clarified.

Regarding the ***categorization and quantification*** of environmental impacts, both concepts rely on the LCA impact assessment methodology. As a consequence, the strengths and weaknesses of LCAI are fully adopted. *Not all impacts can be quantified and attributed to single materials/products*. Still there are no sufficiently harmonized methods to account for the biodiversity losses, or for eco-toxicity impacts, to mention only two types of impacts.

Regarding the "impacts" calculated in LCA these may refer to so-called mid-points or end-points. Mid-point categories are identical to the pressures in the DPSIR-framework used at the macro level (e.g. GWP, ODP, eutrophication). End-point categories are deaths of people or species extinction. In order to calculate end-point categories a number of assumptions must be met which can hardly be verified. Mid-point impact categories seem much more reliable and rather undisputed.

The ***normalization*** of the quantified specific impacts (e.g. GWP, ODP) can be done by dividing the specific pressure values

- by the status quo of the same pressure at the national/EU level (EMC); this indicates the specific contribution of the material/product chain to the specific overall pressure;

- by the policy target for the same pressure at the national/EU level (EVIL); this indicates the specifiy contribution weighted by the policy target, with higher values resulting from lower target values.

The results of the normalization step are values without units, which can be summed up across different impact categories. However, summing them up implies a specific ***weighting between categories***. Without the application of additional factors, equal weighting is performed. This may be more problematic for an indicator such as EMC, whereas it could be acceptable for an indicator such as EVIL, where the target values have already been considered and thus defined the political priorities. In any case this requires the availability of policy targets for the different specific impact categories. EMC may also apply specific weighting, for instance, based on expert judgement taken from ad-hoc councils.

A recently started research project, commissioned by JRC-Ispra, and conducted by PE-International and the Wuppertal Institute is going to provide LCA-based macro indicators for three groups:

- impacts of resource use: the available data for the specific pressures at the country level are combined with the available data for those pressures for all imports and exports;
- impacts of products: a product basket of environmentally most relevant products is defined, and LCA impacts are related to domestic production plus imports minus exports;
- impacts of waste management: impacts for a selection of waste streams are determined.

This project will also have to deal with the LCA specific problems mentioned above, however, it intends to cover the socio-industrial metabolism much more comprehensive than by using a selection of consumed base materials.

Research towards an overall indicator of environmental impacts of resource use is ongoing.

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2 Issues for discussion

In order to clarify the further development of the raw material productivity indicator of the German SD strategy, and possible supplements and extensions by a set of other material flow based indicators, a discussion of the candidate indicators by means of certain criteria is necessary.

With respect to the main target questions to be answered for policy support the following criteria are of prior importance:

A: Main criterion:

Do the underlying concepts and theoretical foundations ensure direction safety with regard to

(a) progress towards sustainable resource use,

(b) with regard to generic or specific environmental impacts?

B: Secondary criteria:

(1) Is practicability given with regard to

(a) data availability

(b) effort for compilation and regular up-date

(c) robustness of data, considering accuracy and uncertainties?

(2) Is the methodological basis solidly described, and practical guidance available?

(3) Is international comparability given and/or can harmonisation be developed?

The candidate indicators will have to be assessed against these criteria.

3 Indicator briefs

The following indicator briefs address the material flow indicators DMI, DMC, TMR, TMC and RME and the impact oriented indicators EVIL and EMC.

The briefs have been compiled by Wuppertal Institute (DMI, DMC, TMR, TMC), together with CML (EMC), and by Ifeu (RME, EVIL).

3.1 Direct Material Input – DMI

3.1.1 Definition

“Direct Material Input (DMI) – measures the direct input of materials for use into the economy, i.e. all materials which are of economic value and are used in production and consumption activities; DMI equals domestic used extraction plus (direct) imports.” (Eurostat 2001).

3.1.2 Objectives

DMI stands for the direct material use for production and consumption of the economy, ie the flow (amount per year) of materials entering manufacturing for domestic consumption or export, or for direct final consumption; it covers fossil fuels, biomass, metallic minerals, industrial and construction minerals; the inflow of DMI determines the amount of subsequent wastes and emissions from manufacturing and households, mainly in the reporting country, partly in the countries receiving the exports produced from DMI.

DMI does not contain unused domestic extraction and indirect resource flows of imports. It does not indicate specific environmental impacts.

3.1.3 Conceptual and methodological foundation

Conceptual foundation

DMI is an indicator derived from economy-wide Material Flow Accounting, which is based upon the concept of socio-industrial metabolism (e.g. Fischer-Kowalski 1998).

Methodological foundation

The basic methodology for setting up economy-wide material flow accounts and derived indicators has been manifested by Eurostat in 2001. Recent and still ongoing developments concern harmonisation with the System of National Accounts (SNA), and practical guidance for deriving the data and indicators for direct materials to be laid down in a joint Eurostat/OECD Implementation Guide (Eurostat 2009). International and national use of the methodology have been and are harmonised (Destatis is represented in the Eurostat MFA Task Force where decisions related to methodological development are prepared and decided).

3.1.4 Practical application

International
Eurostat has published on NewCronos[2] a data set of material flows for the EU-27, its Member States, Switzerland and Norway for the period 2000 to 2005. Also the OECD has published material flow data for its Member Countries. Besides, several national statistical institutes published material flow data and indicators –some even on a regular basis. And, some research institutes keep their own data bases, like the Wuppertal Institute, the IFF a.o.

National
The Federal Statistical Office Germany (Destatis) publishes annually, in autumn, material flow data under the heading "raw materials" (eg in 2009 with data for 1994 to 2007 – data back to 1991 can be obtained from older publications). These data are in line with the Eurostat standard. DMI can be aggregated from the totals of the categories "used domestic extraction" plus "imports of products by degree of manufacturing". (http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Navigation/Publi kationen/Fachveroeffentlichungen/UGR,templateId=renderPrint.psml__nnn=true)

Effort for compilation (includes effort for DMC)

The timeframe for deriving the DMI (and DMC) indicator depends on prior knowledge and preparation. Ideally, a hands-on training workshop has been attended and one is familiar with both the practical implementation guide and the MFA questionnaire. In this case, time requirement is mainly determined by data availability (sometimes complicated by data transfer between different departments, or by necessary contacts with external experts), quality control of the data and plausibility checks. Given rather ideal conditions, a first compilation for DMI (and DMC) may require 3 to 4 person months. For subsequent work on these indicators 1 to 2 person months might be sufficient (depending also on methodological developments which could lead to necessary revisions of the former database).

Data availability

In the best case, DMI is set up by national statistics possibly involving national experts for the critical cases like construction minerals and fodder requirements of livestocks. The following table provides an overview of the most advanced DMI data sets currently available, including providers (OECD and Eurostat) and coverage. These data sets are freely available for everyone. The Eurostat data are planned to be updated bi-annually through a Eurostat ew-MFA Questionnaire sent out to National Statistics Institutes

[2] http://epp.eurostat.ec.europa.eu/portal/page/portal/environment/data/database

(NSI), and the next data update is expected for 2010. Eurostat currently does not provide data for the EU aggregates because of missing, respectively inconsistent data for extra-EU imports by countries. Furthermore, Eurostat does not publish the data for Luxembourg and The Netherlands, as well as for Italy 2004 and Malta 2000-2003. Besides, there are also data available for China and some other Non-OECD countries (OECD 2008). Furthermore, some NSI have their own data base with partly more detailed material flows data and longer time series (e.g. the Federal Statistical Office Germany with data for 1991 to 2007 as of 2009 – see above).
In case DMI (and DMC) is set up from international databases one may refer to recommendations given in the Eurostat compilation guidelines (Eurostat 2009). In short, domestic extraction used can be derived from Eurostat or FAO statistics, and/or from mineral statistics of the British Geological Survey (BGS) or the U.S. Geological Survey (all available for free). Important is that data are in line with the Eurostat accounting principles, and checked for plausibility by applying the check procedures outlined in Eurostat 2009. Data for foreign trade (here imports for DMI, concerns also exports for DMC) of EU member countries can be obtained from the Eurostat Comext online database (for free) and should be sorted by major material groups according to the structure given in Eurostat 2009. Imports (and exports) by non-EU countries can be taken either from national foreign trade statistics (if accessible) or from the international UN Comtrade database which, however, requires conversion of some units to metric tonnes and respective experience of the compilers. Partly, foreign trade data are also available from the FAO online database (biomass) and from IEA energy statistics and BGS or USGS mineral statistics (fossil fuels, metals, non-metallic minerals). However, data for highly manufactured commodities need to be taken from foreign trade statistics.

Tab. 3-1: DMI data available from the Eurostat and OECD data bases

	Direct Material Input (DMI)		
	OECD Data set	Eurostat Data set	
	1980, 1990, 2000, 2005	1970-2000	2000-2005
Canada			
Mexico			
USA			
Japan			
Korea			
Australia			
New Zealand			
EU-27			
EU-15			
Austria			
Belgium	includes Luxembourg	includes Lux.	
Bulgaria			
Cyprus			
Czech Republic			
Denmark			
Estonia			
Finland			
France			
Germany			
Greece			
Hungary			
Iceland			
Ireland			
Italy			2000-2004
Latvia			
Lithuania			
Luxembourg			
Malta			2004-2005
Netherlands			
Norway			
Poland			
Portugal			
Romania			
Slovakia			
Slovenia			
Spain			
Sweden			
Switzerland			
Turkey			
UK			

Data sources:
OECD Environmental Data Compendium: Material Resources:
http://www.oecd.org/document/49/0,3343,en_2649_34441_39011377_1_1_1_1,00.html
Eurostat NewCronos:
http://epp.eurostat.ec.europa.eu/portal/page/portal/environment/data/database

Robustness, accuracy

The concept of MFA has been developed since the early 1990s, towards an internationally harmonised basis (OECD 2008 – Vol. I). Still, a consistent and internationally harmonised method to derive data truly comparable across countries and consistent with the SNA/SEEA is under development by Eurostat and OECD. Uncertainties mainly arise through non-standardised and insufficient data in particular for biomass and construction materials. Once the standardisation methods have been successfully implemented, which should be accomplished within the next two years (end of 2011), the results should be more accurate and robust enough to allow meaningful comparison and interpretation also of the major components of DMI across countries and time. DMI is not additive across countries. For example, for EU totals of DMI the intra-EU foreign trade flows must be netted out from the DMIs of Member States. (Eurostat 2001).

3.1.5 Relation to impacts

DMI does not explicitely cover specific environmental impacts associated with material resource use like acidification. It is, however, between countries correlated with TMR which represents an indicator of generic environmental pressure. It may also be correlated with other specific pressures or pressure indices such as EMC. In any case DMI cannot capture life-cycle related impacts sufficiently as indirect flows of imports are not considered.

3.1.6 Policy relevance

GDP/DMI can measure (direct) material productivity (OECD 2008). DMI can thus be used to indicate the decoupling of direct material use from economic growth. Direct material productivity indicates how much economic value could be produced per unit of material input by domestic production and consumption activities, including the materials used for export (which corresponds to the fact that export contributes significantly to GDP). In 2003, the Japanese government adopted its Fundamental Plan for Establishing a Sound Material-Cycle Society (SMS). The Plan includes three quantitative time-bound targets to be achieved by the year 2010 compared to 2000, one of which is to improve resource productivity (GDP/DMI) by 40% (OECD 2008).

3.1.7 Scientific relevance

There are many scientific publications dealing with material flow indicators including DMI. An overview is given, for example, in OECD 2008, Schütz and Bringezu 2008, Bringezu et al. 2009.

3.1.8 Development requirements and perspectives

DMI is a clearly defined indicator derived from a well established concept and methodology. Development requirements are for full harmonisation of methodology and data with SNA/SEEA principles and for fully standardised data acquisition across countries. The perspectives to reach these goals are good in view of combined efforts undertaken by Eurostat, OECD, UN and international experts in the field.

References

Bringezu, S. / van de Sand, I. / Schütz, H. / Bleischwitz, R. / Moll, S. (2009): Analysing global resource use of national and regional economies across various scales. In: Bringezu, S. and Bleischwitz, R. Sustainable Resource Management – Global trends, visions and policies, p.10-51. Greenleaf Publishing. Sheffield.

Eurostat (2001): Economy-wide material flow accounts and derived indicators. Luxembourg.

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Fischer-Kowalski, M. (1998): Society's metabolism: The intellectual history of material flow analysis. Part I, 1860-1970. Journal of Industrial Ecology 2.1: 61-78. OECD (2008): Measuring material flows and resource productivity: Volume I. The OECD Guide; Volume III. Inventory of Country Activities. Paris.

Schütz, H. / Bringezu, S. (2008): Resource consumption of Germany – indicators and definitions. Federal Environment Agency (Umweltbundesamt), Dessau-Roßlau/Germany. UBA-Texte 08/08.

3.2 Domestic Material Consumption – DMC

3.2.1 Definition

Domestic material consumption (DMC) measures the amount of material directly used in an economy for its own consumption. DMC is defined in the same way as other key physical indictors such as gross inland energy consumption. DMC equals DMI minus exports (Eurostat 2001).

3.2.2 Objectives

DMC stands for the direct material resource basis for consumption of the economy, ie all material input within one year to manufacture or import products for domestic consumption. The volume of DMC will be released sooner or later as processed waste or emissions on the territory of the country.

DMC, like DMI, does not contain unused domestic extraction and indirect material flows of imports and exports. It does not explicitely indicate environmental impacts.

3.2.3 Conceptual and methodological foundation

Conceptual foundation

DMC is an indicator derived from economy-wide Material Flow Accounting, which is based upon the concept of socio-industrial metabolism (see DMI).

Methodological foundation

The basic methodology for setting up economy-wide material flow accounts and derived indicators has been manifested by Eurostat in 2001. Recent and still ongoing developments concern harmonisation with the System of National Accounts (SNA), and practical guidance for deriving the data and indicators for direct materials to be laid down in a joint Eurostat/OECD Implementation Guide (Eurostat 2009). International and national use of the methodology have been and are harmonised (Destatis is represented in the Eurostat MFA Task Force where decisions related to methodological development are prepared and decided).

3.2.4 Practical application

International

Eurostat has published on NewCronos[3] a data set of material flows for the EU-27 and its Member States, and for Switzerland and Norway for the period 2000 to 2005. Also the OECD has published material flow data for its Member Countries. Besides, several national statistical institutes published material flow data and indicators –some even on a regular basis. And, some research institutes keep their own data bases, like the Wuppertal Institute, the IFF a.o.

National

The Federal Statistical Office Germany (Destatis) publishes annually in autumn material flows data under the heading “raw materials” (eg in 2009 with data for 1994 to 2007 – data back to 1991 can be obtained from older publications). These data are in line with the Eurostat standard. DMC can be derived from DMI as described above minus the total of the category “exports of products by degree of manufacturing”. http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Navigation/Publikationen/Fachveroeffentlichungen/UGR,templateId=renderPrint.psml__nnn=true

Effort for compilation

The timeframe for deriving the DMC indicator has been included here in the effort for the DMI indicator as both indicators are usually accounted in one procedure (see above under DMI).

Data availability

The following table provides an overview of the most advanced DMC data sets currently available, including providers (OECD and Eurostat) and coverage. These data sets are freely available for everyone. The Eurostat data are planned to be updated bi-annually through a Eurostat ew-MFA Questionnaire to National Statistics Institutes (NSI), the next data update is expected for 2010. Contrary to DMI, the data for EU-15 and EU-27 can be derived from the totals of the individual Member States’ DMC. Eurostat currently does not publish the data for Luxembourg and The Netherlands; for Italy only for 2004 and Malta 2000-2003. Besides, there are also data available for China and some other Non-OECD countries (OECD 2008). Furthermore, some NSI have their own data base with partly more detailed material flows data in longer time series (e.g. the Federal Statistical Office Germany).

[3] http://epp.eurostat.ec.europa.eu/portal/page/portal/environment/data/database

Tab. 3-2: DMC data available from the Eurostat and OECD data bases

	Domestic Material Consumption (DMC)		
	OECD Data set	Eurostat Data set	
	1980, 1990, 2000, 2005	1970-2000	2000-2005
Canada			
Mexico			
USA			
Japan			
Korea			
Australia			
New Zealand			
EU-27			
EU-15			
Austria			
Belgium	includes Luxembourg	includes Lux.	
Bulgaria			
Cyprus			
Czech Republic			
Denmark			
Estonia			
Finland			
France			
Germany			
Greece			
Hungary			
Iceland			
Ireland			
Italy			2000-2004
Latvia			
Lithuania			
Luxembourg			
Malta			2004-2005
Netherlands			
Norway			
Poland			
Portugal			
Romania			
Slovakia			
Slovenia			
Spain			
Sweden			
Switzerland			
Turkey			
UK			

Data sources:
OECD Environmental Data Compendium: Material Resources:
http://www.oecd.org/document/49/0,3343,en_2649_34441_39011377_1_1_1_1,00.html
Eurostat NewCronos:
http://epp.eurostat.ec.europa.eu/portal/page/portal/environment/data/database

Robustness, accuracy

See DMI. Contrary to DMI, DMC is additive across countries, for example, the DMC of all EU-27 Member Countries can be added up to DMC of the EU-27 aggregate.

3.2.5 Relation to impacts

DMC does not explicitely cover specific environmental impacts of material resource use. It is, however, between countries roughly correlated with impact indices such as the EMC (van der Voet et al. 2005). In any case DMC cannot capture life-cycle related resource requirements and impacts sufficiently as indirect flows of imports are not considered.

3.2.6 Policy relevance

DMC is currently used by the EC as denominator to derive the headline indicator for "resource productivity" under key challenge 3: sustainable consumption and production (Eurostat 2009), expressed as GDP/DMC (in constant Euro per kg). In view of the same shortcomings as described for the DMI, it is acknowledged by the EC that "DMC is used as a proxy for the more relevant indicator, total material consumption (TMC), which includes upstream hidden flows related to imports and exports of raw materials, finished and semi-manufactured products. The EU level TMC is still under development as only a few Member States are currently able to calculate it. In addition, DMC and TMC are only rough proxies for measuring the overall environmental impact of resource use, as materials have very different impacts on the environment. Further development to depict the environmental impacts of material use is needed. (Eurostat 2009b)"

3.2.7 Scientific relevance

There are many scientific publications dealing with material flow indicators including DMC. See DMI.

3.2.8 Development requirements and perspectives

DMC is a clearly defined indicator derived from a well established concept and methodology. Development requirements are for full harmonisation of methodology and data with SNA/SEEA principles and for fully standardised data acquisition across countries. The perspectives to reach these goals are good in view of combined efforts undertaken by Eurostat, OECD, UN and international experts in the field.

References

Bringezu, S. / van de Sand, I. / Schütz, H. / Bleischwitz, R. / Moll, S. (2009): Analysing global resource use of national and regional economies across various scales. In: Bringezu, S. and Bleischwitz, R. Sustainable Resource Management – Global trends, visions and policies, p.10-51. Greenleaf Publishing. Sheffield.

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Eurostat (2009b): Sustainable development in the European Union - 2009 monitoring report of the EU sustainable development strategy.

OECD (2008): Measuring material flows and resource productivity: Volume I. The OECD Guide; Volume III. Inventory of Country Activities. Paris.

Van der Voet, E. / van Oers, L. / Moll, S. / Schütz, H. / Bringezu, S. / de Bruyn, S. / Sevenster, M., Warringa, G. (2005): Policy Review on Decoupling: Development of indicators to assess decoupling of economic development and environmental pressure in the EU-25 and AC-3 countries. CML report 166, Leiden: Institute of Environmental Sciences (CML), Leiden University - Department Industrial Ecology. www.leidenuniv.nl/cml/ssp/

3.3 Total Material Requirement – TMR

3.3.1 Definition

“Total Material Requirement (TMR) – includes, in addition to DMI, the unused domestic extraction plus the (indirect) material flows that are associated to imports but that take place in other countries. It measures the total ‘material base’ of an economy. Adding indirect flows converts imports into their ‘primary resource extraction equivalent’.” (Eurostat 2001).

3.3.2 Objectives

TMR stands for the total global material resource basis for production and consumption of the economy, ie all primary materials that have been extracted from the natural environment within one year to manufacture products for domestic consumption or export. The relation of domestic and foreign TMR allows to monitor the shift of resource supply and associated environmental burden between regions. TMR may be interpreted as indicator of generic environmental pressure which grows with the turnover of primary materials (analogously to primary energy and water).

TMR does not comprise water and air. It does not indicate specific environmental impacts.

3.3.3 Conceptual and methodological foundation

Conceptual foundation

TMR is an indicator derived from economy-wide Material Flow Accounting, which is based upon the concept of socio-industrial metabolism (see DMI).

Methodological foundation

TMR is a basic constituent and most comprehensive indicator within the framework of economy-wide material flow accounts and derived indicators. The method has been manifested by Eurostat in 2001, and adopted by OECD (2008). Further methodological reference has been provided by Bringezu/Schütz (2001) for EEA and in a couple of consulting projects for national statistics institutes (NSI of Denmark, Finland, UK, Italy, France, Switzerland). Unlike DMI and DMC, there is currently no practical guidance publically available for TMR yet. Most studies draw from earlier work of the Wuppertal Institute (see e.g. Bringezu et al. 2003). Some NSI have implemented the method like the ONS (UK), BFS (Switzerland) IFEN (France), and ISTAT (Italy). Italy has, for instance, also developed the methodology for application to the country’s specific data situation (eg in terms of data available to account for soil excavation), a major publication in this context is Barbiero et al. 2003.

3.3.4 Practical application

International

There are some data sets published once or regularly at national statistics (see below), but there is no central collection of TMR data at the level of an international organisation. A PhD study at University of Cologne used the UN Comtrade database for imports (and exports) along with coefficients of the Wuppertal Institute to account for indirect material flows, plus data for domestic used and unused extraction from the global material flows database of SERI[4], to derive TMR for almost all countries or regions of the world (Dittrich 2008).

National

TMR for Germany has been derived for 1991 to 2004 in a study for the Federal Environment Agency (Schütz and Bringezu 2008) building upon DMI published by Destatis (see above).

Effort for compilation

The timeframe for deriving the TMR indicator builds upon work requirements described for the DMI indicator. Deriving unused domestic extraction and indirect material flows of imports is not yet described in a standard methodological guide with practical guidelines and reference data. Ideally, this work is prepared by contacting and interviewing experts in the field of ew-MFA and in particular for accounting for unused and indirect material flows.

In case of Germany, unused extraction is largely available from statistics and/or estimated using default coefficients, and data for direct imports are available by the detailed structure (HS-CN 6-digits) of the Eurostat foreign trade statistics Comext which allows to estimate indirect flows with the use of coefficients from the Wuppertal Institute, a first compilation for TMR (and TMC in case the same coefficients as for imports are used for exports) may require 5 to 6 person months (including work for DMI resp. DMC). For subsequent maintenance and up-date on these indicators 2 to 3 person months might be sufficient (including DMI and DMC).
For other countries, starting with advanced ew-MFA, which may need develop country specific coefficients, significant preparatory development work will be necessary which might be at the order of 6 to 12 person months involving LCI data expert knowledge (depending on the scope and data availability). Subsequent efforts to maintain and up-

[4] http://www.materialflows.net/

date this LCI database may require at the order of additional 2 to 3 person month per year.

Data availability

The following table provides an overview of the TMR data sets that are currently available, including providers and coverage. Most data sets are freely available for everyone. Another overview of TMR activities across OECD- and Non-OECD-countries is given in OECD 2008. Most data are available through published studies (see e.g. Bringezu et al. 2009b). Official TMR data have been provided by national agencies for France, Italy, Switzerland, and UK. UK provides TMR on an annual basis through its official government statistics[5].

Data for compiling the TMR indicator build upon data required to derive DMI (see above). In addition, data (coefficients) to account for indirect material flows of imports are needed (in case the coefficients approach is chosen what has been the case in TMR studies performed so far). Some of these coefficients are available from the Wuppertal Institute MIT-values database[6]. A rather comprehensive coefficients database, which is further organised after the statistical classification of Eurostat foreign trade statistics to be applicable to direct imports data, is available from Wuppertal Institute on request[7].

[5] http://www.statistics.gov.uk/downloads/theme_environment/EA-June09.pdf

[6] http://www.wupperinst.org/info/entwd/index.html?beitrag_id=437&bid=169

[7] Contact: H. Schütz

Tab. 3-3: TMR data available from data bases

	Total Material Requirement (TMR)	
	Period	Holder
USA	1975 - 2000	World Resources Institute
China	1989 - 2002	Northeastern University, Shenyang
Japan	1975 - 1994	NIES Japan
EU-15	1980 - 2000	Wuppertal Institute
Czech Republic	1990 - 2005	Charles University Environment Center Prague
Denmark	1981, 1990, 1997	National Statistics
Finland	1970 - 2005	Thule Institute, University Oulu
France	1990 - 2006	IFEN France
Germany	1991 - 2004	Wuppertal Institute
Hungary	1992 - 2003	cited in OECD 2008
Italy	1980 - 2004	National Statistics
Netherlands	1975, 1980, 1985, 1990-1993	CML Leiden
Poland	1992, 1995, 1997	Wuppertal Institute
Portugal	2000 - 2002	cited in OECD 2008
Spain	1995 - 2000	National Statistics
Sweden	1993 - 1998	cited in OECD 2008
Switzerland	1990 - 2006	National Statistics
UK	1970 - 2007	National Statistics

Robustness, accuracy

Concerning the direct material part of TMR - refer to the DMI indicator above. Unused domestic extraction data can be of very different quality across countries, being either available from official (mining) statistics or based on estimates by e.g. using derived coefficients for another country. Coefficients to derive indirect material flows of im- and exports mostly refer to specific production systems (like Germany, the EU or World) and, like most LCI data, would need to be up-dated to represent technological development over time. Nevertheless, sensitivity analysis shows that the order of magnitude of TMR can be accounted for with sufficient accuracy (in particular when compared to GDP accounting). Providing TMR the way described has been found to be a suitable indicator for the total global material resource use of an economy also by national statistical institutes in France, Italy, Switzerland and the UK. TMR, like DMI, is not additive across countries. TMR of the EU can only be derived from the extra-EU trade of the European Union by including their indirect material flows. Regarding the existing official data for TMR, comparability across countries is not yet fully granted because some countries did include soil erosion in TMR (which, according to Eurostat 2001, should be treated as a memorandum item and not be included in the indicator) and some did not; some did not account in a sufficient way for earth excavation (for construction works) and dredging; while others used insufficient coefficients database for indirect flows of biomass products.

3.3.5 Relation to impacts

TMR does not explicitely cover impacts of resource use. However, as it measures total primary resource extraction it can be interpreted as indicator of generic environmental pressure which is associated with the turnover of these flows in the affected environment (Bringezu et al. 2003, 2009). The amount of TMR equals the amount of wastes and emissions from mining to final waste disposal. It determines the magnitude of landscape changes by mining, infrastructure development and waste deposition.

3.3.6 Policy relevance

GDP/TMR measures total resource productivity of a country (OECD 2008). Among the material flow indicators derived from ew-MFA, TMR represents the most comprehensive resource use indicator for the physical basis of an economy that generates its wealth (GDP) from global resources, while providing goods and services for final domestic final consumption and exports. A quantitative, time-bound policy target addressing TMR has been set up in Italy to achieve a reduction of the total material requirement (TMR) of 25% by 2010, 75% by 2030 and 90% by 2050 (Environmental Action Plan for sustainable development in Italy). TMR is used as an indicator to monitor progress of the promotion of Resource Efficiency in Japan through 3R (Reduce, Reuse and Recycle) policies.

3.3.7 Scientific relevance

There are a couple of scientific publications dealing with material flow indicators including TMR. Overviews are given, for example, in Bringezu et al. 2003, Schütz and Bringezu 2008 and OECD 2008.

3.3.8 Development requirements and perspectives

TMR is a clearly defined indicator derived from a well established concept and methodology within the Eurostat/OECD ew-MFA framework. Further international implementation will require guidance for full harmonisation of methodology and the provision of reference data across countries. NSI are expected to account for domestic unused extraction after having established DMI/DMC, also to provide sufficient information on waste flows. For the consideration of indirect flows of imports, to reach a similar level of accuracy like in Germany, NSI would need assistance in the form of a data base with coefficients for internationally traded products (Giljum et al. 2008).

References

Barbiero, G. / Camponeschi, S. / Femia, A. / Greca, G. / Macrì, A. / Tudini, A. / Vannozzi, M. (2003): 1980-1998 Material-Input-Based Indicators Time Series and 1997 Material Balance of the Italian Economy, ISTAT, Rome.

Bringezu, S. / Schütz, H. / Moll, S. (2003): Rationale for and Interpretation of Economy-wide Material Flow Analysis and Derived Indicators. Journal of Industrial Ecology, Vol. 7, no. 2, p. 43-64.

Bringezu, S. / Schütz, H. / Saurat, M. / Moll, S. / Acosta-Fernández, J. / Steger, S. (2009b): Europe's resource use. Basic trends, global and sectoral patterns and environmental and socioeconomic impacts. In: Bringezu, S. and Bleischwitz, R. Sustainable Resource Management – Global trends, visions and policies, p.10-51. Greenleaf Publishing. Sheffield.

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OECD (2008): Measuring material flows and resource productivity: Volume I. The OECD Guide; Volume III. Inventory of Country Activities. Paris.

Schütz, H. / Bringezu, S. (2008): Resource consumption of Germany – indicators and definitions. Federal Environment Agency (Umweltbundesamt), Dessau-Roßlau/Germany. UBA-Texte 08/08.

3.4 Total Material Consumption – TMC

3.4.1 Definition

Total material consumption (TMC) measures the total primary material use for domestic consumption, including unused extraction and indirect flows of imports, excluding indirect flows of exports. TMC equals TMR minus exports and their indirect flows (Eurostat 2001).

3.4.2 Objectives

TMR stands for the total global material resource basis for the consumption of an economy, ie all primary materials that have been extracted from the global environment within one year to manufacture products for domestic consumption. The relation of TMC to the exports and their indirect flows indicates how much of the TMR is associated to domestic consumption vs. being used to produce the exports. TMC can be used for international comparisons of per capita global resource consumption of countries.

TMC does not comprise water and air inputs. The indicator is not designed to capture specific environmental impacts.

3.4.3 Conceptual and methodological foundation

Conceptual foundation

TMC is an indicator derived from economy-wide Material Flow Accounting, which is based upon the concept of socio-industrial metabolism (see DMI).

Methodological foundation

TMC is a basic constituent and most comprehensive indicator within the framework of economy-wide material flow accounts and derived indicators. The method has been manifested by Eurostat in 2001, and adopted by OECD (2008). Further methodological reference has been provided by Bringezu/Schütz (2001) and in a couple of consulting projects for national statistics (Denmark, Finland, UK, Italy, France, Switzerland). Contrary to DMI and DMC, there is currently no practical guidance in public available for TMC. Most studies draw from earlier work of the Wuppertal Institute (see e.g. Bringezu et al. 2003). A recent study by WI, SERI and GWS (2008) has proposed to apply a combination of methods, ie the coefficients approach (see TMR) and a model-based input-output approach, to derive the TMC indicator in a more comprehensive way.

3.4.4 Practical application

International

There are some data sets published once or regularly at national statistics (see below), but there is no central collection of TMC data at the level of an international organisation. A PhD study at University of Cologne proposed the use of the UN Comtrade database for imports and exports along with coefficients of the Wuppertal Institute to account for indirect material flows, plus data for domestic used and unused extraction from the global materialflows database of SERI (http://www.materialflows.net/), to derive TMC for almost all countries or regions of the world (Dittrich 2008).

National

TMC for Germany has been derived for 1991 to 2004 in a study for the Federal Environment Agency (Schütz and Bringezu 2008) building upon DMC published by Destatis (see above) and using the coefficients approach. The above mentioned combined CA and IO method to derive TMC has been applied as an example to account for the TMC of Germany in 2000 (WI et al. 2008).

Effort for compilation

The timeframe for deriving the TMC indicator builds upon work requirements described for the TMR indicator. Requirements for TMC are similar to TMR in case the coefficients approach is chosen. In case TMC is derived through input-output calculation or via a global multi-regional input-output model, time requirements depend on the availability of such tools.

Data availability

The following table provides an overview of the TMC data sets that are currently available, including providers and coverage. Most data sets are freely available for everyone through published studies (see e.g. Bringezu et al. 2009b). Official TMC data are available for France, Italy, and Switzerland. It is quite obvious that data coverage for TMC is less than for TMR. A major reason is that people refrained from applying the same coefficients for indirect material flows of exports as for imports. On the other hand, only few accountants are experienced to use input-output calculation to derive TMC estimates this way.

Data for compiling the TMC indicator build upon data required to derive DMC (see above) and are similar to what has been written about TMR in case the coefficients approach is followed. Using a global IO model is restricted to related experts (GWS in the case of Germany – see WI et al. 2008).

Tab. 3-4: TMC data available from data bases

	Total Material Consumption (TMC)	
	Period	Holder
USA	1991	World Resources Institute
EU-15	1980 - 2000	Wuppertal Institute
Czech Republic	1990 - 2005	Charles University Environment Center Prague
Denmark	1981, 1990, 1997	National Statistics
Finland	1970 - 2005	Thule Institute, University Oulu
France	1990 - 2006	IFEN France
Germany	1991 - 2004	Wuppertal Institute
Italy	1980 - 2004	National Statistics
Netherlands	1975, 1980, 1985, 1990-1993	CML Leiden
Spain	1995 - 2000	National Statistics
UK	1970 - 2007	National Statistics

Robustness, accuracy

Concerning the direct material part of TMC refer to the DMC indicator above. For unused domestic extraction and coefficients to derive indirect material flows of imports see the discussion under TMR. Official TMC data are available for France, Italy, and Switzerland. Comparability across countries is, however, not necessarily granted, for the same reasons as described above for TMR. A specific task for TMC is the calculation of the indirect material flows of exports which can be achieved (1) as first approximation by using the same coefficients as for imports; by establishing country specific coefficients, either by (2) LCA type approaches (MIPS analysis), or (3) using input-output techniques, or (4) applying a multi-regional global input-output model like the Global Resource Accounting Model (GRAM) of GWS Osnabrück/Germany (Wuppertal Institute et al. 2008). Using (1) is rather unspecific but is supposed to deliver still a rough and direction safe estimate. (2) requires LCA data banks covering unused extraction. Using (3) and (4) is hampered by less details for materials which may differ significantly by their magnitude of indirect flows, with (4) being naturally restricted to the use by the model owner, while (3) requires special input-output skills.

3.4.5 Relation to impacts

See TMR.

3.4.6 Policy relevance

TMC has been proposed by the European Commission as denominator (GDP/TMC) for the headline (or level-1) indicator “Resource productivity” under the theme 2 “Sustainable Consumption” (Sub-theme 'Resource use and waste'), indicating the extent of decoupling of material consumption from economic growth in terms of GDP (see reference under DMC above).

One may argue that TMC should be used for measuring absolute resource consumption which can be compared on a per capita basis, whereas TMR would be more adequate to measure resource productivity (GDP/TMR) because it covers all resources used for production, including those for exports (which contribute significantly to GDP).

3.4.7 Scientific relevance

There are a couple of scientific publications dealing with material flow indicators including TMC. Overviews are given, for example, in Bringezu et al. 2003 and 2009b and OECD 2008.

3.4.8 Development requirements and perspectives

TMC is a clearly defined indicator derived from a well established concept and methodology within the Eurostat/OECD eMFA framework. Further implementation will require further refinement for determination of the indirect material flows part. Results from the INDI-LINK project (Wuppertal Institute et al. 2008) showed that the best methodology should make use of the major advantages of the two major approaches which are the high level of detail for the coefficients approach (CA), and the fact that indirect resource requirements can be calculated for all types of products, independent from the level of manufacturing by the input-output approach (IO). A future best available method will thus likely combine the coefficient approach for a selected number of raw materials and semi-manufactured products with an IO approach for higher-manufactured products (where the IO approach should apply a multi-regional IO-MFA model). The perspectives of further development are depending on research funding and decisions to provide the indicator by official statistics..

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3.5 DMI and DMC measured as Raw Material Equivalents – RME[8]

3.5.1 Definition

The DMI and DMC measured as Raw Material Equivalents also follow closely the general definition as given in the boxes above. The conventional DMI and DMC include domestic used extraction plus (direct) imports respectively (direct) exports. The RME corrected DMI and DMC include additionally the (used) raw materials extractions associated with the imported and exported materials and goods.

3.5.2 Objectives

DMI and DMC as RME represent the direct and indirect material use for the production and consumption of all goods manufactured in an economy or imported into the economy (DMI-RME) or only consumed in an economy (DMC-RME). It treats imported and exported goods as if they were entirely extracted domestically or – in other words – the production of finished goods is considered with all the material inputs (this could be expressed as material backpack) in the country of origin (export country). Similar to the uncorrected DMI and DMC it covers the same types of raw materials.

DMI and DMC do not contain unused extractions whether domestic or imported. It does not indicate specific environmental impacts but may represent them.

3.5.3 Conceptual and methodological foundation

Conceptual foundation

DMI and DMC are indicators derived from economy-wide Material Flow Accounting but are corrected on the basis for the imports and exports with process data from the specific production of goods (process-chain-thinking) or with the application of national production figures (from IOTs) to the imports and exports

Methodological foundation

In the concept of the conventional DMI the domestic extractions and imports are treated differently. While the domestic extractions include all direct and indirect used material (e.g. metal ore) the imported goods are taken into account with their real mass entering the frontiers of an economy (e.g. refined metal). The uncorrected DMI adds up domestically extracted raw materials to imported refined and finished goods. In order to solve this inhomogeneous approach the imported goods (exported goods for DMC) are corrected with the (used) material extraction which has occurred in the country of pro-

[8] provided by IFEU

duction. This approach has been suggested in national and international discussions (Schoer 2006, Schoer 2008, Giegrich 2008, Buyny 2009) and is currently tested for EU 27.

3.5.4 Practical application

National

A research project for measuring the raw material productivity of Germany showed the unsymmetrical treatment of national extraction and import (UBA 2006). The mere addition of e.g. domestically extracted metal ore and imported refined metals demonstrated the difficulty to interpret the conventional DMI (respectively DMC). Consequently UBA commissioned two studies to give practical solutions on how to include externally extracted material which is related to the imports to Germany (or exports from Germany in the case of DMC). Destatis and IFEU-Institut developed two different approaches how to calculate Raw Material Equivalents for imports and exports and apply them to the national MFA system.

International

Comparable approaches for correcting the DMI and DMC with Raw Material Equivalents had been found in the Czech Republic and in Austria. They had been presented in a conference in Prague in 2008. Eurostat commissioned a study to apply the RME correction for the DMI and DMC of EU 27 in 2009 to a consortium of IFEU-Institut, SSG and Charles University Prague. It is in the stage of research how the correction can be applied under given data sources in Europe.

Effort for compilation

Firstly the DMI and DMC corrected with RME includes all the efforts described above for the conventional DMI and DMC. They are the starting point for the correction. Depending on the applied methodology for the correction a medium to large number of processes must be modelled in process chains. The information for process models is not easily available and their data quality differs considerably. So a high effort has to be assumed for starting the correction and a moderate effort is needed to update the information about processes after some years. If procedures can be made automatic the effort besides the process modelling upfront can be considered as moderate. But it is premature to finally judge about the effort for compilation of DMI and DMC corrected with RME.

Data availability

As already stated the RME corrected DMI and DMC requires all the basic statistical data as described in the chapters above for uncorrected DMI and DMC.

Then it additionally needs information on how a set of basic raw materials is manufactured in the countries importing to an economy. In the case of economies with small stocks of raw materials like the EU mainly the metals are imported. Therefore they need a modelling on how much raw materials are extracted and used to produce e.g. a given amount of refined metal which is imported into the EU. In principle an average of raw material production of the different countries imported to an economy is needed. It is difficult and costly to generate these data due to the need of detailed information. Nevertheless data banks exist (e.g. EcoInvent) which provide some information with different degrees of data quality and completeness.
For the application of IOT (one approach) to generate the RME it is necessary to know the flows of the raw materials through the national economy which is used as a pattern for the external production for finished products. In this case appropriate statistical information is needed. Besides metals the information for the production of biomass which can only be produced in e.g. tropical countries (e.g. bananas) is necessary and cannot be derived solely from a national IOT of the importing country.

Robustness, accuracy

The concept of RME corrected DMI and DMC is fairly new and needs further research to understand the robustness and accuracy of the calculations.

3.5.5 Relation to impacts

Also the RME corrected DMI and DMC do not cover directly environmental impacts. Nevertheless it can be demonstrated that a certain representation of some impacts is given. While energy related impacts (Global warming, eutrophication, etc.) correlate better with the corrected DMI and DMC this is not easily the case to e.g. water related emissions or land use.

3.5.6 Policy relevance

GDP/DMI is used in the German context to measure raw material related aspects. The political goals like a raw material efficient economy can only be monitored with the help of such indicators. The deficient methodology of the conventional DMI and DMC requires an appropriate correction of the concept.

3.5.7 Scientific relevance

First publications especially at the MFA Conference in Prague are available (ConAccount 2008). The research work has to be evaluated and will be in the case of RME corrections a matter of further debate.

3.5.8 Development requirements and perspectives

The RME corrected DMI and DMC will play an important role for a methodological sound measurement of resource use. Therefore it is necessary to further improve the method and increase the data quality for relevant materials. Only after the evaluation of ongoing research it can be concluded which methodology in detail will be chosen. Obviously a mixture of IOT and process chain thinking is needed to achieve the goal. It is open to discussion which degree of detail is necessary for a sound measurement of a national raw material efficiency.

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3.6 Environmental Impact Load – EVIL[9]

3.6.1 Definition

EVIL stands for Environmental Impact Load. It is a uniform measurement unit which combines different impacts which affect environmental safeguard subjects like climate, air quality, water quality, etc. while using raw materials (or economic activities in general).
1 EVIL can be understood as the acceptable maximum of environmental impacts which guarantee the sustainable development of society (related to a country for the time being) (Giegrich, Liebich, 2008).

3.6.2 Objectives

The objective for the application of EVIL is to use an aggregated environmental indicator which encompasses different impacts and threats to environmental safeguard subjects. It combines scientific knowledge with societal value judgements and conventions laid down by democratically legitimized institutions (e.g. Government).

EVIL is based on political conventions (decisions) which may undergo changes over time. Therefore the quantification can be subject to changes – according to existing and developing knowledge and existing value judgements. The EVIL concept is not representing environmental impacts but is an aggregate of different impacts acting on environmental safeguard subjects.

3.6.3 Conceptual and methodological foundation

Conceptual foundation

The approach is based on the concept of Sustainable Development which is understood with the definition of the Brundtland Report (1987) further developed in the Agenda 21 from the Rio Conference (1992). The environmental part of the Brundlandt definition for Sustainable Development defines the carrying capacity of the Earth which must be complied with under the pressure of human activities. The carrying capacity is deducted from existing knowledge and from subjective but legitimated value judgements.

Methodological foundation

The impact on the environment by the use of raw materials is the basis for the indicator and must be linked to the safeguard subjects and their specific carrying capacity. Safe-

[9] provided by IFEU

guard subjects are defined in national and international sustainability concepts and normally comprise e.g. climate, air quality, water quality, human health, quality of soil and land including also biodiversity.

Wherever it is possible environmental quality goals can be adopted as the carrying capacity of the single safeguard subject. As a next step it is necessary to link the economic activities regarding the use of raw materials – calculated in the statistical accounting systems – with the environmental safeguard subjects. The DPSIR concept can be used to connect the safeguard subjects (state of the environment) to the economic activities and the related environmental pressures. So pressures of economic activities have to be related to impacts and the carrying capacity of each safeguard subject.

The general idea is shortly described with an example:
The environmental goal to reduce global warming (safeguard subject: climate) is not to exceed 2°C of additional warming. With this goal a certain concentration of greenhouse gases in the atmosphere is defined and consequently a limit for the emissions of greenhouse gases (environmental pressure) on a yearly basis can be calculated. Then it is a political decision which country of the world as a whole has to contribute how much to this reduction of emissions. For example: Germany is emitting about 1,000 Mio t of CO_2 equivalent – the quality goal is that Germany should not emit more than 250 Mio.t.
With the help of these environmental goals for the selected safeguard subject it is possible to define a common unit which is called “Environmental Impact Load – EVIL”. The definition of this unit is:

1 EVIL = the quantity of a pressure for which the long-term and sustainable protection of a safeguard subject can just be granted (carrying capacity)

For the safeguard subject climate and for the situation of Germany it can be stated:
1 EVIL = 250 Mio t CO_2-equivalent per year

Now the CO_2-equivalents of any economic or human activity which can be derived from the MFA or NAMEA/IOT will be expressed in this unit. The mechanism behind this calculation is a weighting according to a distance-to-target scheme. The larger the distance of the actual pressure to the environmental quality goal the higher will be the weight of the respective pressure.

This scheme could be applied for all safeguard subjects which are selected. Environmental quality objectives can be formulated at the level of pressures, the level of environmental state or the level of environmental impacts.

3.6.4 Practical application

National and International

Several conventions have to be agreed and used. This is easier to establish in the political situation of a single country. It is more difficult to achieve political decisions at an international level but not impossible. The following conventions are needed:

- selection of safeguard subjects
- selection which impacts or substances (emissions) can potentially harm the safeguard subject
- find environmental quality goals which ensure the carrying capacity of this safeguard subject
- agree on the equal value of each safeguard subject (or divert from this)

Effort for compilation

This indicator needs as a basis the mass flows in an economy which is the national MFA data – expressed as DMI and DMC. Then all selected environmental pressures and impacts are needed for the detail of the national MFA. This is partly existing in NAMEA tables. Additional pressures and impacts (e.g. emissions to water bodies; land use) must be measured throughout a country and its sectors if they are needed additionally.

Data availability

The most important impacts and pressures are readily available in the context of environmental discussions (greenhouse gases, acidifying gases, etc.) Others are not easily available but should be known if considered to be important.

Robustness, accuracy

The robustness is based on the accuracy of the input data like mass flows and the measured environmental impacts and pressures. Robustness and accuracy are the wrong expressions to evaluate the political settings of environmental quality goal. Here it is necessary to have a democratic process to define the carrying capacity.

3.6.5 Relation to impacts

It is not the purpose of this indicator to represent all possible impacts or pressures. The EVIL concept is an aggregate of the selected impacts or pressures in relation to the different environmental safeguard subjects.

3.6.6 Policy relevance

No policy relevance is given so far because the EVIL concept is a suggestion on how to assess the use of raw material in a broader sense. It only can gain relevance if democratic institutions are willing to define environmental quality goals (carrying capacity) and accept the way how they are used in this valuation concept.

3.6.7 Scientific relevance

Little scientific relevance because the EVIL concept is a first proposal which must be further discussed and refined. But it contains important elements to be useful in the future.

3.6.8 Development requirements and perspectives

Environmental quality goals are needed to guide policy making. If they don't exist (as partly today) no guidance for a sound policy on Sustainable Development is given. As social preferences and political decisions are involved discussions about the right selection of safeguard subjects and environmental goal has to be promoted. In the longer run a refinement of the weighting methodology appears to be useful.

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3.7 Environmentally weighted Material Consumption – EMC[10]

3.7.1 Definition

EMC provides an aggregate measure of the life-cycle-wide environmental impacts associated with the domestic material consumption of (a set of) selected materials. 13 available impact categories (GWP, ODP etc.) per unit of material use are normalized with data on status quo of a reference year on the global level; these normalized impact coefficients are multiplied with the apparent consumption of the material; To arrive at one score, the 13 impact categories have to be aggregated using weighting, which can be done is various ways. EMC has been applied for the EU and member states based on roughly 30 materials and using various weighting schemes (van der Voet et al. 2005).

3.7.2 Objectives

EMC aims to measure potential life-cycle-wide environmental impacts of the consumption of materials, focussing on the cradle-to-gate and waste-recycling stages of the life-cycle, and including direct emissions of the material in the use phase only. The energy requirement of the use phase of products is covered indirectly, via the impacts of consumed fossil fuels.

EMC covers only a selection of materials, and therefore does not capture environmental impacts of materials not accounted for.
EMC does not cover all environmental impacts, as there are no harmonized LCA conventions to deal with land use/land cover-change related impacts or depletion of resources, especially biotic resources.

3.7.3 Conceptual and methodological foundation

Conceptual foundation

EMC is an indicator embedded in the concept of socio-industrial metabolism (like DMC) and based on LCA methodology which aims at quantifying life-cycle-wide environmental impacts of products.

Methodological foundation

The basic methodological reference for EMC is the study report “Policy review on decoupling” for DG Environment and its annexes (van der Voet et al. 2005) which also provide some practical guidance for deriving the indicator.

[10] provided by Wuppertal Institute with kind contribution of Ester van der Voet (CML)

3.7.4 Practical application

The EMC indicator has been derived so far for the EU-25 and its member countries plus the – then – 3 accession and candidate countries which were Bulgaria, Romania and Turkey; in time period from 1992 to 2000.

Effort for compilation

The timeframe for deriving the EMC indicator depends on the basic approach chosen, ie if one starts with the DMC indicator and derives the apparent material consumption data from it (as done in the original EMC study), or if one uses apparent material consumption data from available statistics directly. The latter should be a more efficient approach given data availability. The application of LCA coefficients usually requires expert knowledge, and the amount of additional work to derive the EMC clearly depends on the availability of LCIA coefficients, and the requirements to use up-to-date and region specific data. The application of impact factors, once derived, is straightforward and takes hardly any time at all. In a setting where annual statistics are collected stardardly and available impact factors can be used, EMC calculation can take place routinely. When balance sheets for materials have to be compiled specifically, or new impact factors have to be derived, this is a more time consuming matter. Region specific data are presently scarce and scattered. Collecting region specific data is a constant point of attention of the LCA community.

Data availability

Availability of materials data has been described for DMC. LCI data are available in professional data bases like Ecoinvent. For establishing the impacts to derive EMC, the CMLCA software (Heijungs, 2003) and an established LCA database, the ETH database (Frischknecht, 1996) were used in the 2005 study. Since then, impact factors are updated using the Ecoinvent database (Ecoinvent, 2008).

Robustness, accuracy

Van der Voet et al. describe interpretation problems of the EMC: “The uncertainties of basic MFA data and the derived DMC also apply to the EMC. Additional uncertainties and restrictions arise from the use of LCA data. The LCA process data are averages for Western Europe, implying that on the one hand differences between countries are not expressed, while on the other hand efficiency improvements over time that do not result in a lower materials consumption (such as the application of end-of-pipe technologies) cannot be seen. The LCA database is updated once a decade rather than once a year. Basic assumptions in the LCA database with regard to recycling and allocation are difficult to detect and may be open for improvement. Regarding the LCA impact assessment data, there are large differences in quality between the different impact categories. While global warming potentials are based on internationally agreed studies, large uncertainties exist in the impact categories related to toxicity. The LCA Impact Assessment methodology is not well developed for land use and waste generation. Depletion of resources of a biotic nature, e.g. wood and fish, is not included at all; at this moment there is no consensus on how to derive impact factors. Despite these omissions and uncertainties, the addition of LCA data in our view is still relevant, bringing the MFA based indicator a step further in the direction of potential impacts. Both for MFA and LCA databases, improvements should and probably will be made over time, allowing for more reliable indicators. Both research and development areas are alive and many experts are working on it, which ensures a highly dynamic development field."

3.7.5 Relation to impacts

EMC has explicitely been developed to account for impacts of material use, some limitations have been described above.

3.7.6 Policy relevance

The development of EMC was commissioned by DG Environment in order to develop an economy-wide indicator which could describe in a quantitative manner the decoupling of environmental impacts of global resource use from economic growth by the EU. In other words, EMC was meant to represent the "overall environmental impacts line" of the Thematic Strategy on the use of natural resources of the Commission (EC 2003). Since then, it has been the subject of a study commissioned by the EC to compare different decoupling indicators (Best et al., 2008). It has been recommended as one of the four indicators in a "basket of indicators" supporting resource policy, to be compiled on a regular basis in the Eurostat Datacenter on Natural Resources. A study has been commissioned by Eurostat to update EMC and assess whether EU statistics can be used directly, instead of using MFA accounts (van der Voet et al., 2009). This proved to be possible. In a draft Implementation Plan, EMC is proposed as one of the indicators of the "Environmental Sustainability Dashboard" of the EU, supporting the Resource Strategy (Dige, in press)

3.7.7 Scientific relevance

No information.

3.7.8 Development requirements and perspectives

Since the pioneering study by van der Voet et al. (2005), there have been attempts to develop impact based resource use indicators at Eurostat and in Germany (see EVIL). Recently the JRC-IES, Ispra, has launched a study with the aim to develop life cycle based macro-level monitoring indicators on resources, products and wastes for the EU-27.

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